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TECHNICAL REPORT ARLCD-TR-83027

DETERMINATION OF NONPROPAGATION DISTANCE FOR M74AP AND M75AT-AV MINES

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MAY 1983

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER
WEAPON SYSTEMS LABORATORY
DOVER, NEW JERSEY

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

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M74AP/M75AT-AV mines
RDX explosive
GEMSS-LAP
MMT-Ammunition

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

As part of an Army-wide expansion and modernization program, the safe-separation distance for production of M74AP and M75AT-AV mines was studied, tested, and determined in a series of tests. The results were used to establish safety criteria for new manufacturing load-assemble-pack (LAP) facilities and also existing facilities under renovation. The program to determine the necessary minimum nonpropagation distance was drafted by ARRADCOM and was subsequently conducted in two separate phases. (cont)

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The exploratory phase consisted of a total of 12 separate tests, some without and some with barricades, using one donor mine and two acceptor mines. The confirmatory test phase consisted of 25 tests, 50 acceptors with the test conditions held constant. The results confirmed that zero spacing (19.7 cm/ 7.8 in. centerline distance) using a 7.6 cm (3.0 in.) thick 6061-T6 aluminum barrier between mines will sufficiently deter the possibility of propagating an explosive incident. Four tests using a 7.6 cm (3.0 in.) square barrier, the full width of the conveyor, were conducted in order to preclude the necessity of accurate mine alignment.

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ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to the following individuals for their participation, guidance and cooperation during the performance of this program: Messrs. D.M. Kogar and R. Brack of the ARRADCOM Resident Operations Office, National Space Technology Laboratories, Mississippi, for their preparation of the detailed test plans and the coordination of the actual testing program; and to Messrs. R. Amend, S. Fuentes, L. Mars, H. Stover and G. Richardson of the Hazard Range Support Unit, Computer Science Corporation, NSTL Station, Mississippi, for the execution of the test series and the basic data collation of same.

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INTRODUCTION

Background

At the present time, an Army-wide Modernization and Expansion Program is currently underway for the purpose of upgrading existing and developing new Load-Assemble-Pack (LAP) manufacturing explosive facilities. This effort will enable such facilities to achieve increased production cost effectiveness with improved safety, as well as provide manufacturing facilities for new improved weaponry within existing LAP manufacturing facilities.

As part of the overall modernization and expansion program, the Special Technology Branch, Energetic Systems Process Division, LCWSL of ARRADCOM, Dover, New Jersey, is engaged in the development of system safety criteria in support of ammunition plant LAP operations.

An essential component of this program, titled "Safety Engineering in Support of Ammunition Plants", is the development of safe separation (non-propagation) distance criteria for munition end-items, sub-components and bulk explosive materials. Such criteria, when developed under this program, will be utilized as the basis for the design of all new explosive production installations as well as the modernization of existing ones.

The activities encompassed within this technical report will provide safety criteria data to specifically support modernization provisions for the establishment of new, high volume LAP facilities for the manufacture of M74AP and M75AT-AV Mines at Iowa Army Ammunition Plant, Middletown, Iowa. Since LAP operational plans for said high volume production line was not available for pre-test review and analysis, the test conditions were based upon the mines going individually along a standard conveyor system. Also, since both types of mines will utilize the same basic production line, and the M75AT-AV Mine contains the greatest amount of explosive materials, it was selected to determine the safe separation distance for both mines.

Objective

The primary objective of this program is to determine experimentally the minimum safe (non-propagating) separation distances between M74AP and M75AT-AV Mines as they are transported between assembly operations on a conveyor system. The data obtained from this program will help determine the safe separation distance between mines on the conveyor system, conveyor speeds and the rate of production of the dual mine system.

The overall program objective is to supplement and/or modify existing safety regulations, and criteria pertaining to the safe spacing of ammunition and other energetic materials in order to assist explosive loading plants in their LAP facility layouts for the most effective and economic man-machine relationships.

Criteria

This test program was implemented to determine the safe spacing between M75AT-AV mines situated individually along a standard conveyor system such that the effects of an accidental detonation of a mine on the assembly line be limited to the immediate area or loading bay, and not be propagated to adjacent loading activities. Therefore, the only acceptable criteria to establish the safe separation distances is the non-propagation of the donor detonation to the acceptors.

Note that all separation distances cited in this report were measured between the axial centerlines of the donor and acceptor mines and/or barriers.

TEST CONFIGURATION

General

The testing of the M75AT-AV Mine to determine the minimum non-propagation distance between donor and acceptor units was initiated and completed during February 1982. All testing was conducted at the National Space Technology Laboratories in Mississippi, under the auspices of the ARRADCOM Resident Operations Office. This was in conjunction with the Hazards Range Support Unit of the Computer Science Corporation.

Initially, the actual test program was to consist of two portions: an exploratory phase to determine the minimum free air non-progragating distance and an ensuing confirmatory phase to statistically establish confidence in the resultant safe separation distance. However, the unbarricaded distance at which detonation propagations still occurred became incompatible with planned LAP layouts and production rates; therefore, a second series of tests were conducted utilizing a barrier between mines.

Test Specimen

The complete M75AT-AV Mine (fig. 1) consisted of a charge case assembly with 590 grams (1.3 pounds) of RDX explosive, two conical shaped charge plates, two cover plates, an S and A mechanism, a booster charge, an electronics assembly, an electric battery primer and various incidental components to complete the mine assembly. In order to greatly reduce test material costs, the electronics assembly and the S and A mechanism were omitted from the test mines (fig. 2). Since the S and A mechanism had previously passed functional safety tests in the "SAFE" position, this was considered a valid omission.

Test Arrangement

Each test layout consists of one donor and two acceptor mines arrayed in a straight line and raised off the ground to simulate the conveyor system's average stand-off distance above the building floor, as shown in figure 3. The center specimen served as the donor, or initiated mine, while the mines on either side served as the acceptor specimens, thus producing two acceptor sets of test data results for each test donor detonated. During the exploratory test phase, the test separation distance between the donor and acceptor mines was varied from test to test, and also within the single test firings. However, during the confirmation test phase, the donor-to-acceptor separation distance was always held constant.

The exploratory phase of the program initially consisted of a test array of three unbarricaded M75AT-AV Mines arranged in a linear position and mounted on a 2.54- by 30.48-centimeter (1.0- by 12.0-inch) pine board to simulate the conveyor system as shown in figure 4. The test mines and simulated conveyor were supported by low density concrete blocks approximately 45.7 centimeters (18.0 inches) above the existing terrain to again fully simulate the LAP facility's conveyor system. During this phase, which consisted of 10 test detonations, the separation distances, measured centerline to centerline between mines, ranged from 0.61 to 6.10 meters

(2.0 to 20.0 feet). A series of confirmatory tests were initiated, but were halted when it was realized that the distances were incompatible with planned LAP layouts and production rates.

A second series of exploratory phase tests were begun, utilizing a 7.6-centimeter (3.0-inch) diameter 6061-T6 aluminum bar cut to the full height of the mines, and located between the donor and acceptor mines on the test centerline. Figures 5 and 6 are side and top views, respectively, of the barricaded test array. Only two exploratory phase tests were conducted at centerline distances ranging from 19.7 to 152.4 centimeters (7.8 to 60.0 inches).

The confirmatory test phase consisted of a series of 25 tests utilizing the barricaded test array with a centerline spacing of 19.7 centimeters (7.8 inches) between mines or zero spacing with both donor and acceptor mines touching the barriers. This spacing was held constant for all the confirmatory tests.

A final test array consisting of a 7.6-centimeter (3.0-inch) square barrier, 30.48 centimeters (12.0 inches) long, the width of the simulated conveyor, was utilized for a series of four tests. Figure 7 is a pre-test view of a test array utilizing this square barrier. This test series was conducted, utilizing excess mines, in order to prove out a barrier that would preclude the accurate conveyor alignment of the mines necessitated by the circular barriers.

Method of Initiation

The donor mine was primed with special electrical detonators that would directly simulate the output of the mines' normal S and A assembly. This insured that the mine always functioned to a high order detonation, which was further confirmed by a steel witness plate under the donor mine.

TEST RESULTS

General

As previously stated, the safe separation distance non-propagation tests of the M75-AT-AV Mines consisted of a two-part exploratory test phase, consisting of barricaded and unbarricaded tests, and a confirmatory test phase to statistically confirm the established distance and barricade type. Also, a final barricade configuration was subjected to a number of tests to determine its non-propagation compatibility with the conveyor system.

Unbarricaded Test Phase

A total of 10 unbarricaded exploratory tests were conducted utilizing various separation distances (measured between mine centerlines), ranging from 0.61 to 6.10 meters (2.0 to 20.0 feet) as shown in table 1, test numbers 1 through 10 inclusive. High order acceptor detonation propagations from the donor detonation occurred up to a spacing of 2.74 meters (9.0 feet) between mine centerlines. Figure 8 is a view of such a test where the detonation of the donor mine has just affected the right hand acceptor mine (main vertical flames); note also the additional fragment impacts around the immediate area.

A confirmatory phase was initiated on the unbarricaded configuration utilizing a distance between mines of 6.10 meters (20.0 feet); however, only four tests were conducted, numbers 1 through 4 inclusive of table 2. Testing was discontinued for two reasons: first and paramount, the 6.10-meter (20.0-foot) distance being established was considered to be completely incompatible with planned LAP layouts and production rates; and second, even at this distance, fragments were fully penetrating the acceptor mines which could eventually lead to the propagation of the donor detonation.

Figures 9 and 10 are two more views of the unbarricaded test phase. Figure 9 shows fragments from the detonated donor impacting on both right and left acceptors; however, in this case, there were only fragment penetrations with no acceptor detonations occurring. Figure 10 is a post-test view of another unbarricaded test. As can be seen from the witness plates, both donor and right acceptor mines functioned with high order detonations, while the left acceptor mine was severely damaged by the fragment impacts.

Barricaded Test Phase

The second series of exploratory tests utilized a 7.6-centimeter (3.0-inch) diameter 6061-T6 aluminum bar cut to the full height of the mines [6.6 centimeters (2.6 inches)] and which was located between the donor and acceptor mines on the test centerline. This barrier was selected due to immediate availability of the material and its proven effectiveness as barriers on other energetic material non-propagation tests. Only two exploratory tests were conducted utilizing various separation distances ranging from a maximum of 1.52 meters (5.0 feet) down to 19.7 centimeters (7.8 inches). This latter distance is the mine-to-mine centerline distance with both mines touching the barricade. Test numbers 11 and 12 of table 1 provide the detailed results of the two barricaded exploratory tests.

The barricaded confirmatory test phase consisted of 25 test detonations involving 50 acceptor mines and yielding 50 valid data points at zero mine spacing [19.7 centimeters (7.8 inches) in centerline distance]. Test numbers 5 through 29 inclusive of table 2 are the detailed results of these tests.

Figures 11 and 12 are post-test views of barricaded tests. The mines, in both cases, have been destroyed by the impact of the blast-driven barrier on them; however, as can be seen in both figures, the composition was not detonated nor even burned, and none of the mines were penetrated by fragments. Also note in figure 12 the amount of fragments absorbed by the recovered barrier.

Square Barrier Test

A final test series was conducted, utilizing a 7.6-centimeter (3.0-inch) square barrier 30.84 centimeters (12.0 inches) long. This barrier, the full width of the simulated conveyor, would preclude accurate alignment of the mines on the conveyor system. A total of four tests were conducted at the zero mine spacing [19.7 centimeters (7.8 inches) centerline distance] without any propagation of the donor's detonation. In the fourth test, a five-mine test array (acceptor, barrier, acceptor, barrier-donor-barrier, acceptor-barrier-acceptor) was utilized with only minor damage to the outer acceptors (cracks in composition) as can be seen in figure 13.

Analysis of Test Results

Variation in manufacturing tolerances, materials, wear, etc., required that statistical methodology be employed when interpreting the confirmatory phase test data. The actual probability of the continuous propagation of an unexpected explosive incident at a LAP facility ammunition production line is a function of the number of propagation occurrences in a particular confirmatory test phase as compared to the total number of test detonations conducted within that phase (see appendix for statistical theory).

In the confirmatory test phase of the M75AT-AV Mine conveyor non-propagation study, a total of 50 valid data points were recorded without a single propagation of a donor detonation utilizing zero mine spacing [19.7 centimeters (7.8 inches) in centerline distance] with a 7.6-centimeter (3.0-inch) thick 6061-T6 aluminum barrier between mines. An upper limit of 7.11 percent probability of propagation of an explosive incident at the 95 percent confident level has been calculated using these aforementioned parameters.

Similarly, in a large number of tests, 95 out of every 100 times an unexpected explosive incident occurs. The probability of it propagating to a catastrophic event will be less than, or equal to, 7.11 percent. This value is an indication of the quality of the test results and the reliance that can be placed upon the conclusions drawn from the data.

CONCLUSIONS

It may be concluded from the results of the M75AT-AV Mine Non-Propagation Program that zero safe separation spacing [19.7 centimeters (7.8 inches) in centerline distance] utilizing a 7.6-centimeter (3.0-inch) thick 6061-T6 aluminum barrier between mines sufficiently deters the probability of propagating an explosive incident. With this arrangement, the probability of the propagation of an explosive incident is 7.11 percent at the 95 percent confidence level.

Table 1. Safe separation distance tests of XM75AT-AV Mines

(Exploratory Phase Summary)

Test No.		Centerline Distance Acceptor cm	(in)	Barrier cm	(in)	Remarks
1	L	61.0	(24.0)	None		HOD[a]
	R	91.4	(36.0)	None		5 Penetrations[b]; all explosive burned
2	L	91.4	(36.0)	None		HOD
	R	106.7	(42.0)	None		50%[c] burn, 10 penetrations, top blown off
3	L	121.9	(48.0)	None		50% burn, 4 penetrations
	R	152.4	(60.0)	None		No burning, 5 penetrations
4	L	182.9	(72.0)	None		No burning, 3 penetrations
	R	213.4	(84.0)	None		HOD
5	L	243.8	(96.0)	None		No burning, 1 penetration
	R	274.3	(108.0)	None		No burning, 2 penetrations
6	L	304.8	(120.0)	None		No damage
	R	335.3	(132.0)	None		2 hits[d]; no penetrations or burning
7	L	243.8	(96.0)	None		Several hits, no penetrations or burning
	R	304.8	(120.0	None		No damage
8	L	243.8	(96.0)	None		No damage
	R	274.3	(108.0)	None		HOD
9	L	304.8	(120.0)	None		No burning, 2 penetrations, top blown off
	R	335.3	(132.0)	None		No burning, 2 penetrations, top blown off, all explosive scattered
10	L	457.2	(180.0)	None		No burning, 1 large penetration, top blown off
	R	609.6	(240.0)	None		No damage
11	L	61.0	(24.0)	30.5	(12.0)[e]	No burning or penetrations, hit by barrier and top blown off
	R	152.4	(60.0)	76.2	(30.0)	No damage
12	L	30.5	(12.0)	15.2	(6.0)	No burning or penetrations, hit by barrier and explosive scattered
	R	19.7	(7.8)	9.8	(3.9)	No burning or penetrations, hit by barrier and explosive scattered

a HOD - High Order Detonation propagated from donor.

b X% burn - Amount of RDX burned.

c Penetrations - Went through outer case into explosive.

d Hits - Marked or lodged within outer case, did not make contact with explosive.

e Barrier consists of a 7.6-cm (3.0-inch) diameter 6061-T6 aluminum rod, cut to the full height of the XM75AT-AV Mine and located on the test centerline.

Table 2. Safe separation distance tests of XM75AT-AV Mines

(Confirmatory Phase Results)

Test No.		Centerline Distance Acceptor cm	(in)	Barrier cm	(in)	Remarks
1	L	609.6	(240.0)	None		NDP[a], no damage
	R	609.6	(240.0)	None		NDP, no damage
2	L	609.6	(240.0)	None		NDP, no damage
	R	609.6	(240.0)	None		NDP, no damage
3	L	609.6	(240.0)	None		NDP, no damage
	R	609.6	(240.0)	None		NDP, no damage
4	L	609.6	(240.0)	None		NDP, 100% burn, 1 large penetration
	R	609.6	(240.0)	None		NDP, no damage
5	L	19.7	(7.8)	9.8	(3.9)[b]	NDP, top blown off, explosive scattered
	R	19.7	(7.8)	9.8	(3.9)	NDP, top blown off, explosive scattered
6	L	19.7	(7.8)	9.8	(3.9)	NDP, top blown off, explosive scattered
	R	19.7	(7.8)	9.8	(3.9)	NDP, top blown off, explosive scattered
7[c]	L	19.7	(7.8)	9.8	(3.9)	NDP
	R	19.7	(7.8)	9.8	(3.9)	NDP
8	L	19.7	(7.8)	9.8	(3.9)	NDP
	R	19.7	(7.8)	9.8	(3.9)	NDP
9	L	19.7	(7.8)	9.8	(3.9)	NDP
	R	19.7	(7.8)	9.8	(3.9)	NDP
10	L	19.7	(7.8)	9.8	(3.9)	NDP
	R	19.7	(7.8)	9.8	(3.9)	NDP
11	L	19.7	(7.8)	9.8	(3.9)	NDP
	R	19.7	(7.8)	9.8	(3.9)	NDP
12	L	19.7	(7.8)	9.8	(3.9)	NDP
	R	19.7	(7.8)	9.8	(3.9)	NDP
13	L	19.7	(7.8)	9.8	(3.9)	NDP
	R	19.7	(7.8)	9.8	(3.9)	NDP
14	L	19.7	(7.8)	9.8	(3.9)[b]	NDP
	R	19.7	(7.8	9.8	(3.9)	NDP

Table 2. (cont)

Test No.		Centerline Distance: Acceptor cm	(in)	Barrier cm	(in)	Remarks
15	L	19.7	(7.8)	9.8	(3.9)	NDP
	R	19.7	(7.8)	9.8	(3.9)	NDP
16	L	19.7	(7.8)	9.8	(3.9)	NDP
	R	19.7	(7.8)	9.8	(3.9)	NDP
17	L	19.7	(7.8)	9.8	(3.9)	NDP
	R	19.7	(7.8)	9.8	(3.9)	NDP
18	L	19.7	(7.8)	9.8	(3.9)	NDP
	R	19.7	(7.8)	9.8	(3.9)	NDP
19	L	19.7	(7.8)	9.8	(3.9)	NDP
	R	19.7	(7.8)	9.8	(3.9)	NDP
20	L	19.7	(7.8)	9.8	(3.9)	NDP
	R	19.7	(7.8)	9.8	(3.9)	NDP
21	L	19.7	(7.8)	9.8	(3.9)	NDP
	R	19.7	(7.8)	9.8	(3.9)	NDP
22	L	19.7	(7.8)	9.8	(3.9)	NDP
	R	19.7	(7.8)	9.8	(3.9)	NDP
23	L	19.7	(7.8)	9.8	(3.9)	NDP
	R	19.7	(7.8)	9.8	(3.9)	NDP
24	L	19.7	(7.8)	9.8	(3.9)	NDP
	R	19.7	(7.8)	9.8	(3.9)	NDP
25	L	19.7	(7.8)	9.8	(3.9)	NDP
	R	19.7	(7.8)	9.8	(3.9)	NDP
26	L	19.7	(7.8)	9.8	(3.9)	NDP
	R	19.7	(7.8)	9.8	(3.9)	NDP
27	L	19.7	(7.8)	9.8	(3.9)	NDP
	R	19.7	(7.8)	9.8	(3.9)	NDP
28	L	19.7	(7.8)	9.8	(3.9)	NDP
	R	19.7	(7.8)	9.8	(3.9)	NDP
29	L	19.7	(7.8)	9.8	(3.9)	NDP
	R	19.7	(7.8)	9.8	(3.9)	NDP

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a NDP - No (donor) Detonation Propagation (to acceptor).

b Barrier consisted of a 7.6-cm (3.0-in) diameter 6061-T6 aluminum rod, cut to the full height of the XM75AT-AV Mine and located on the test centerline.

c All remaining tests had the same remarks as tests nos. 5 and 6, and resultant damages were caused by barrier impact with the acceptor units.

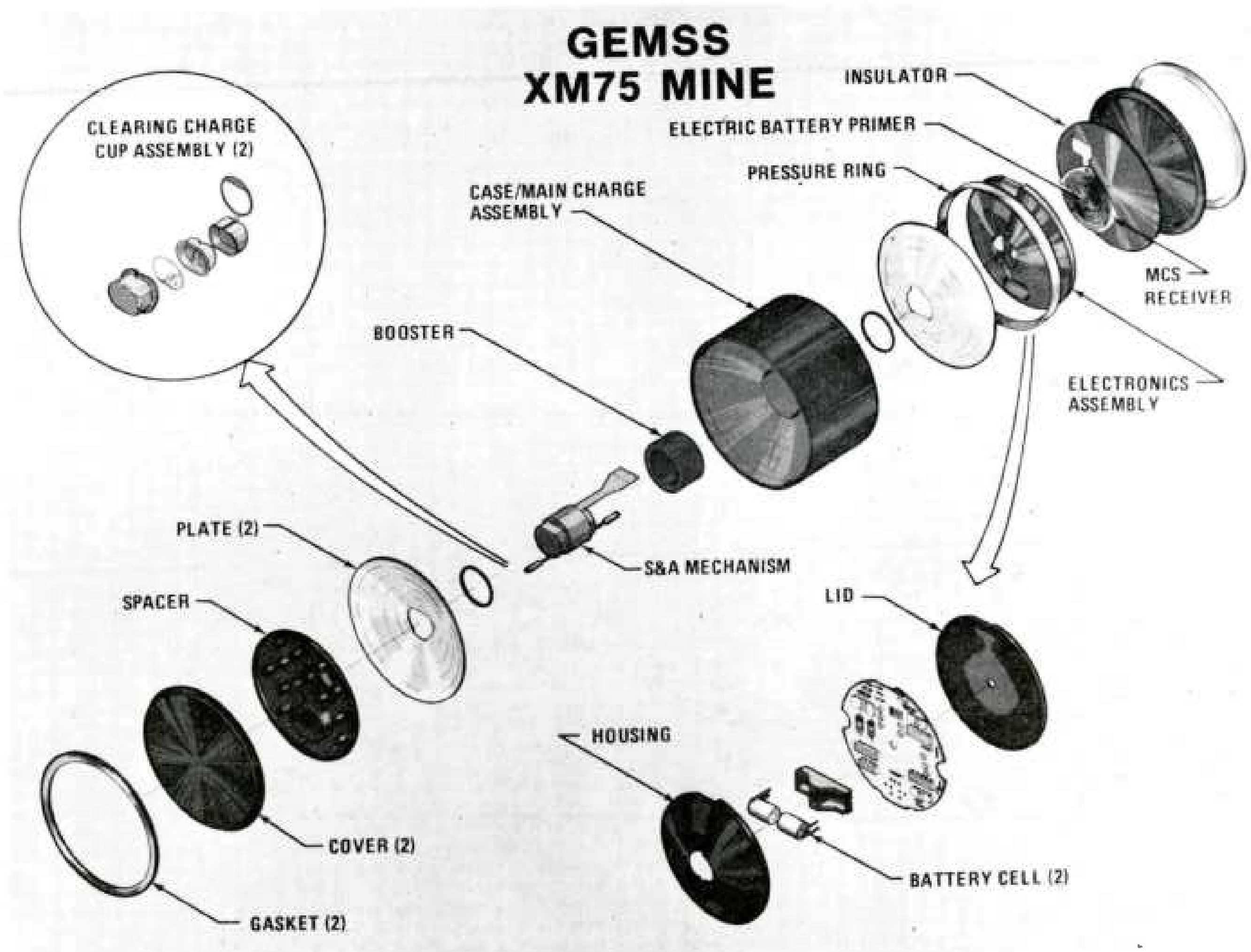

Figure 1. Complete M75AT-AV Mine

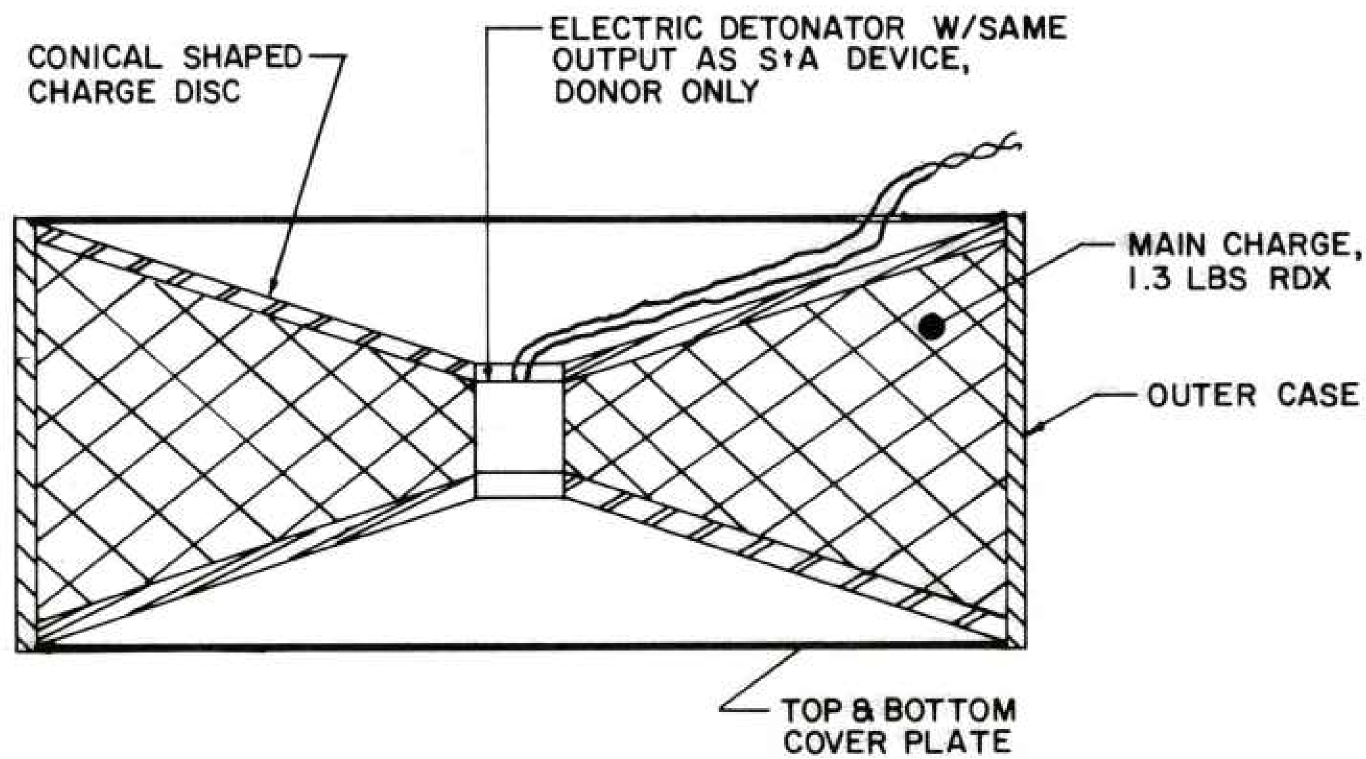

Figure 2. Test modified, M75AT-AV Mine

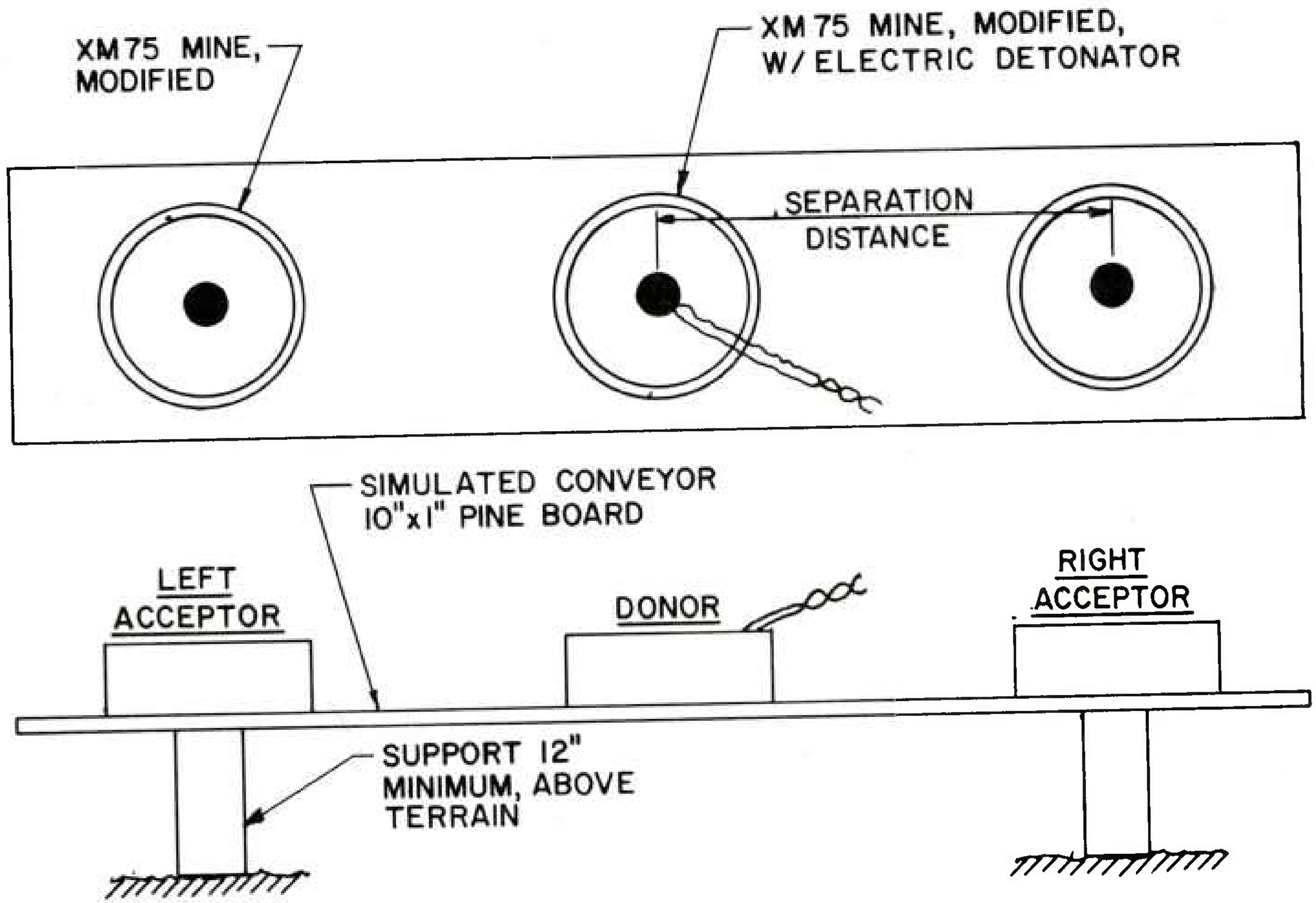

Figure 3. Test array, unbarricaded

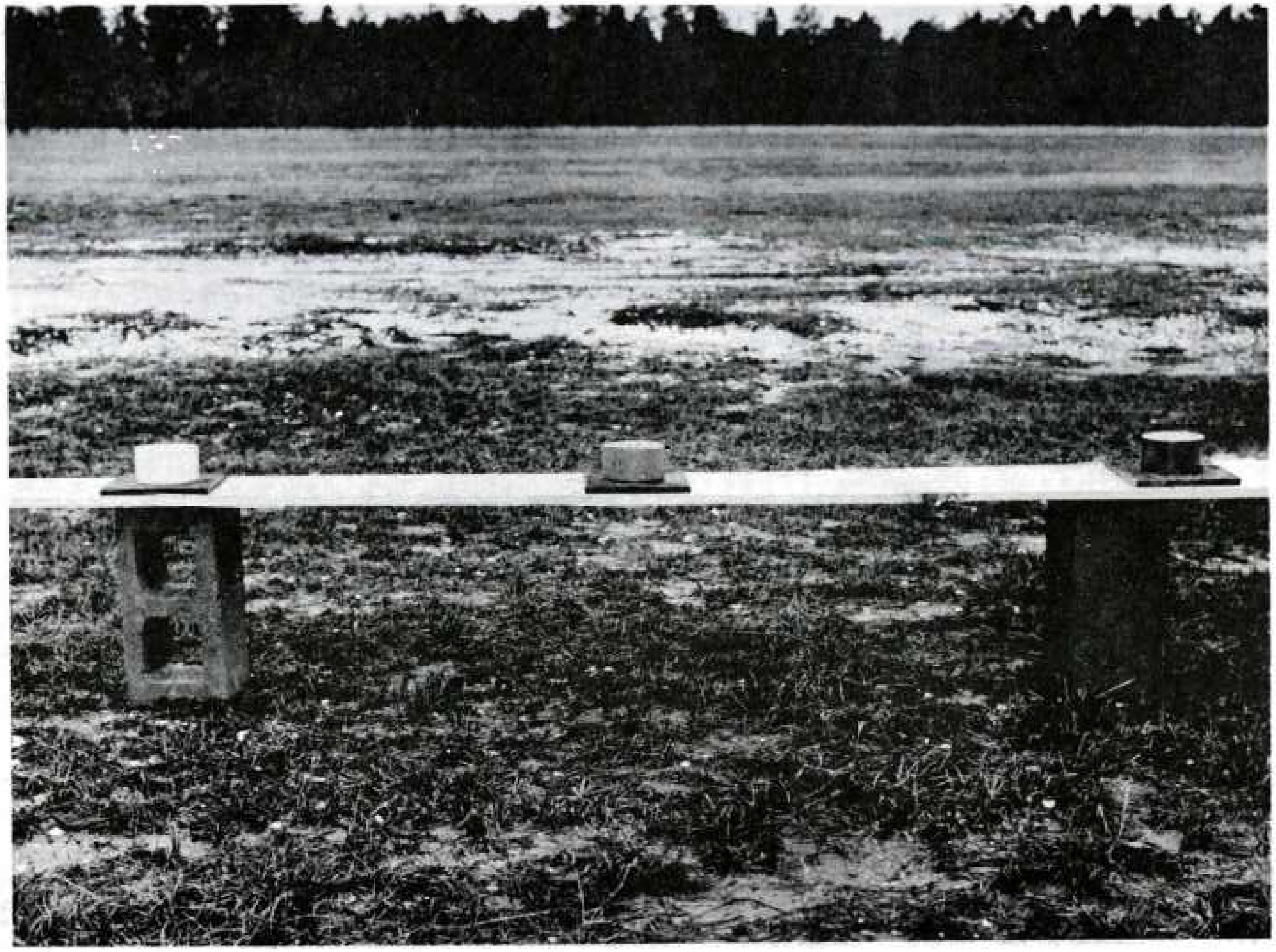

Figure 4. Unbarricaded test array, side view

Figure 5. Barricaded test array, side view

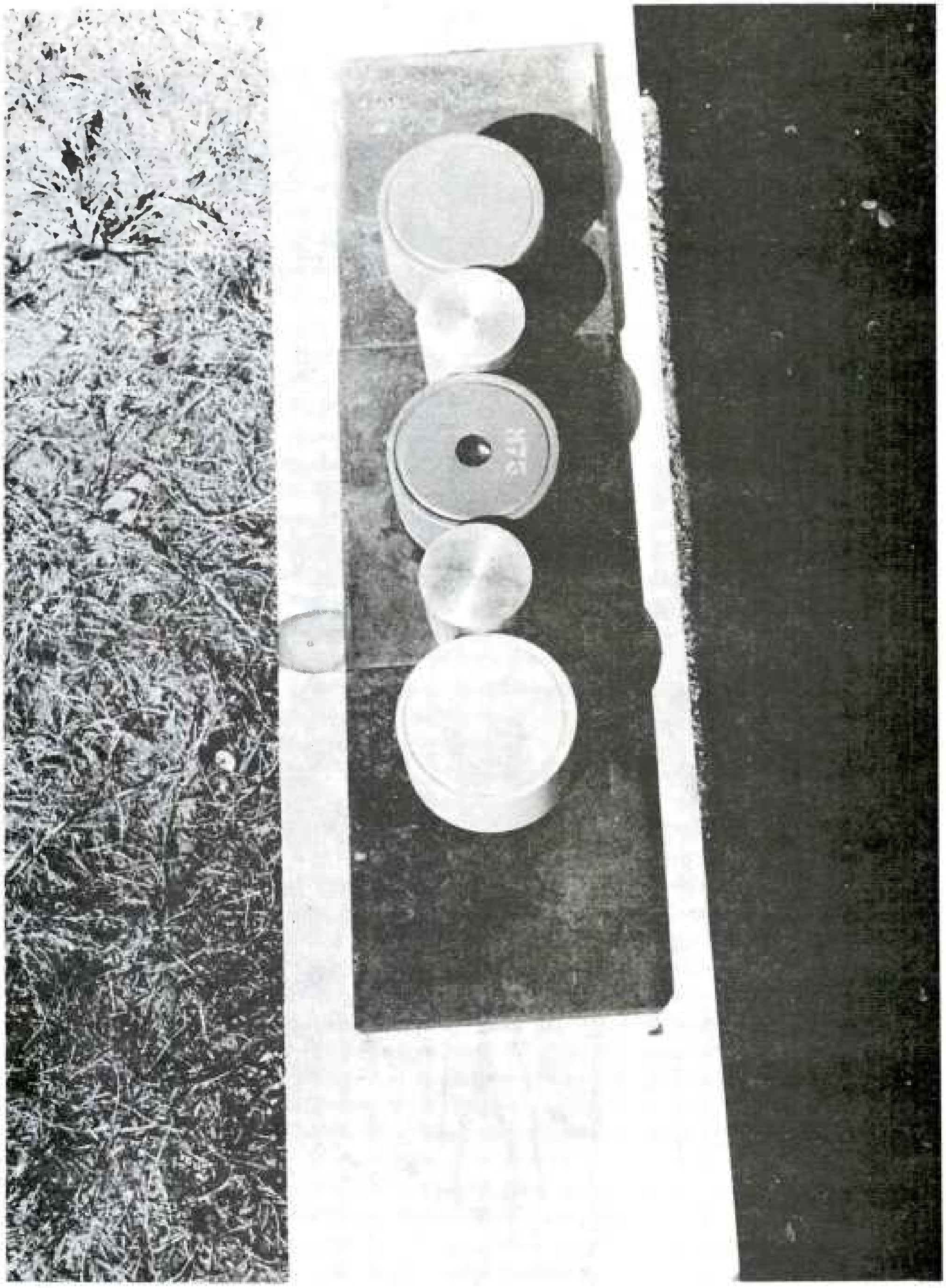

Figure 6. Barricaded test array, top view

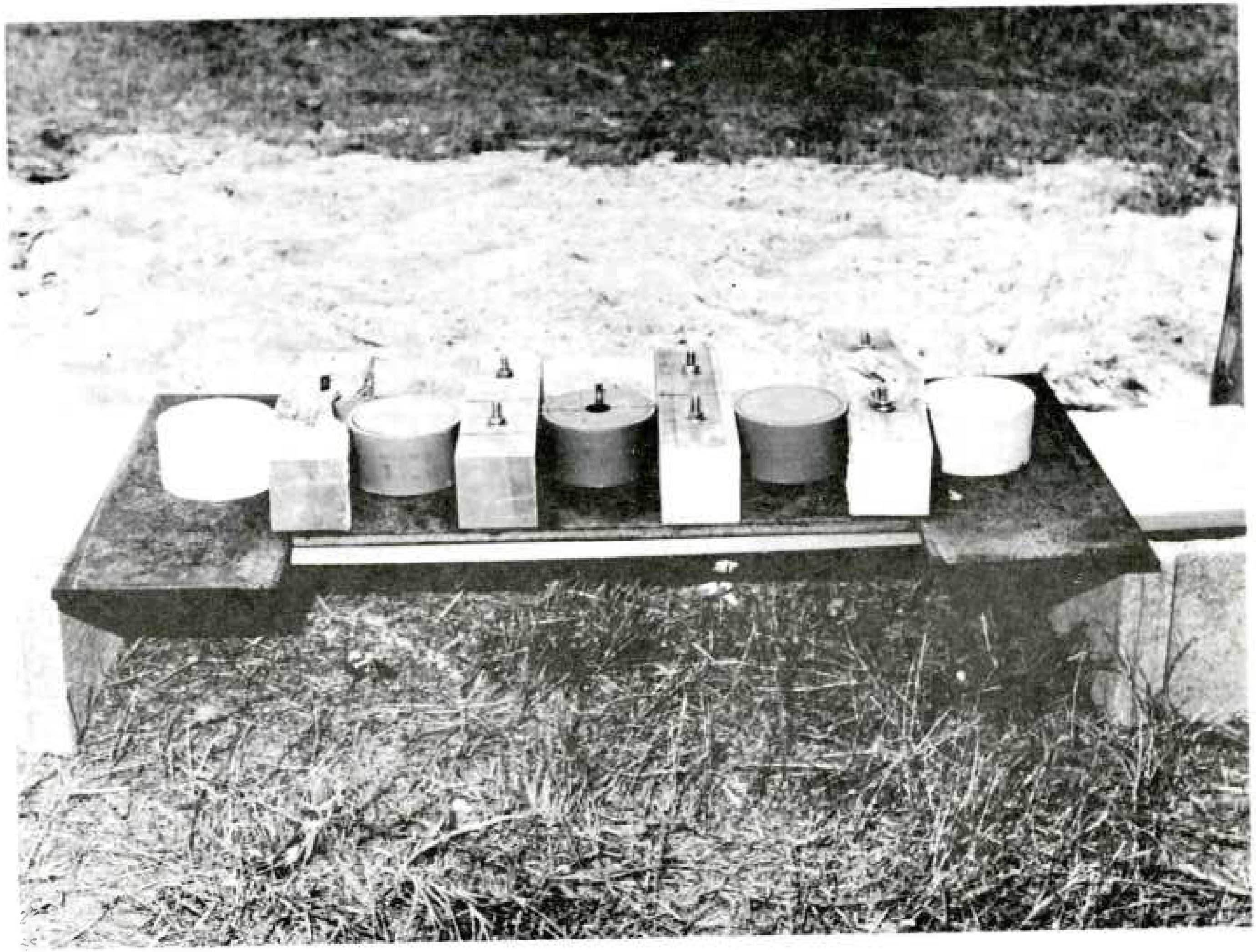

Figure 7. Square barrier test array

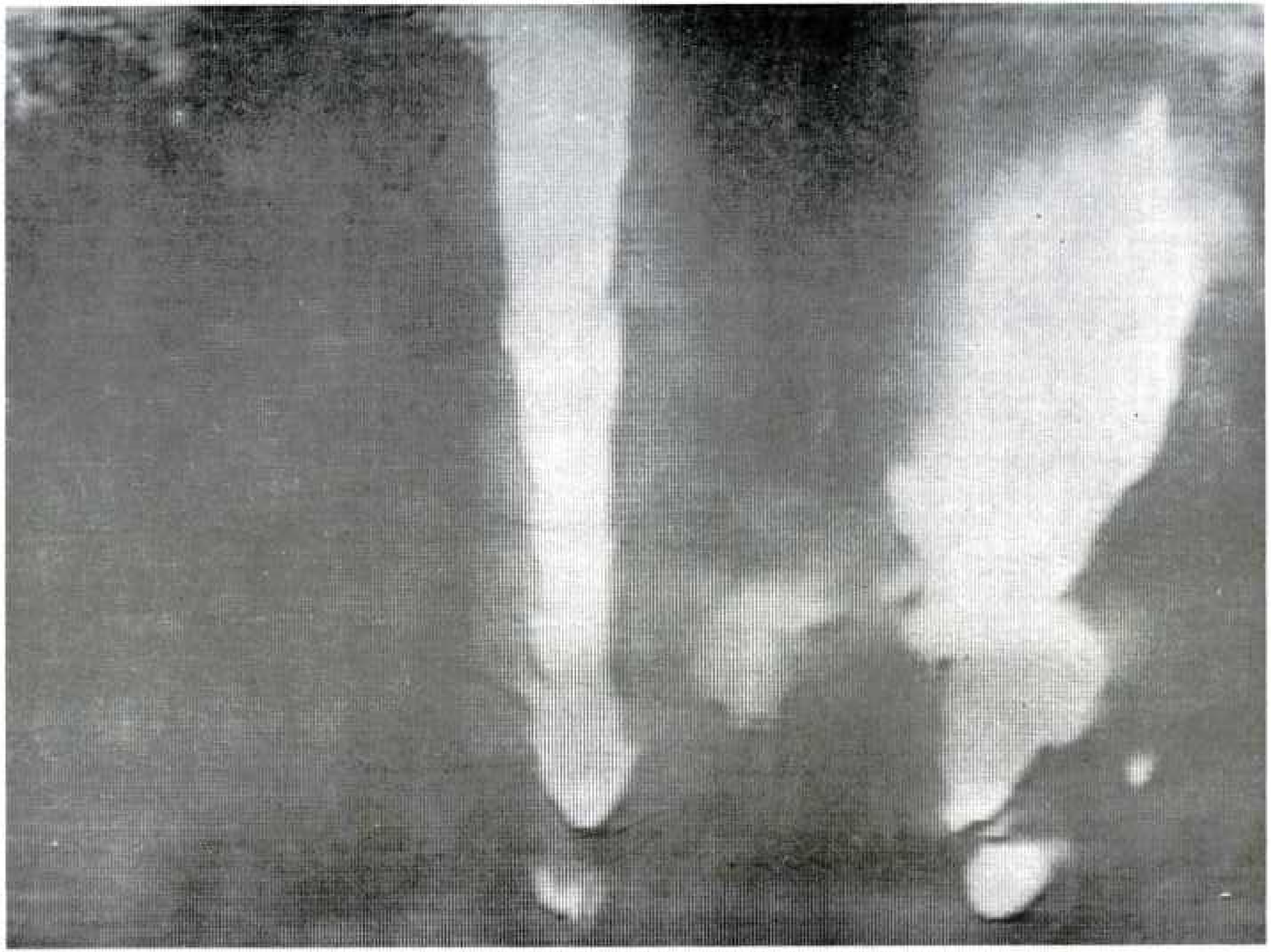

Figure 8. Donor propagation to acceptor

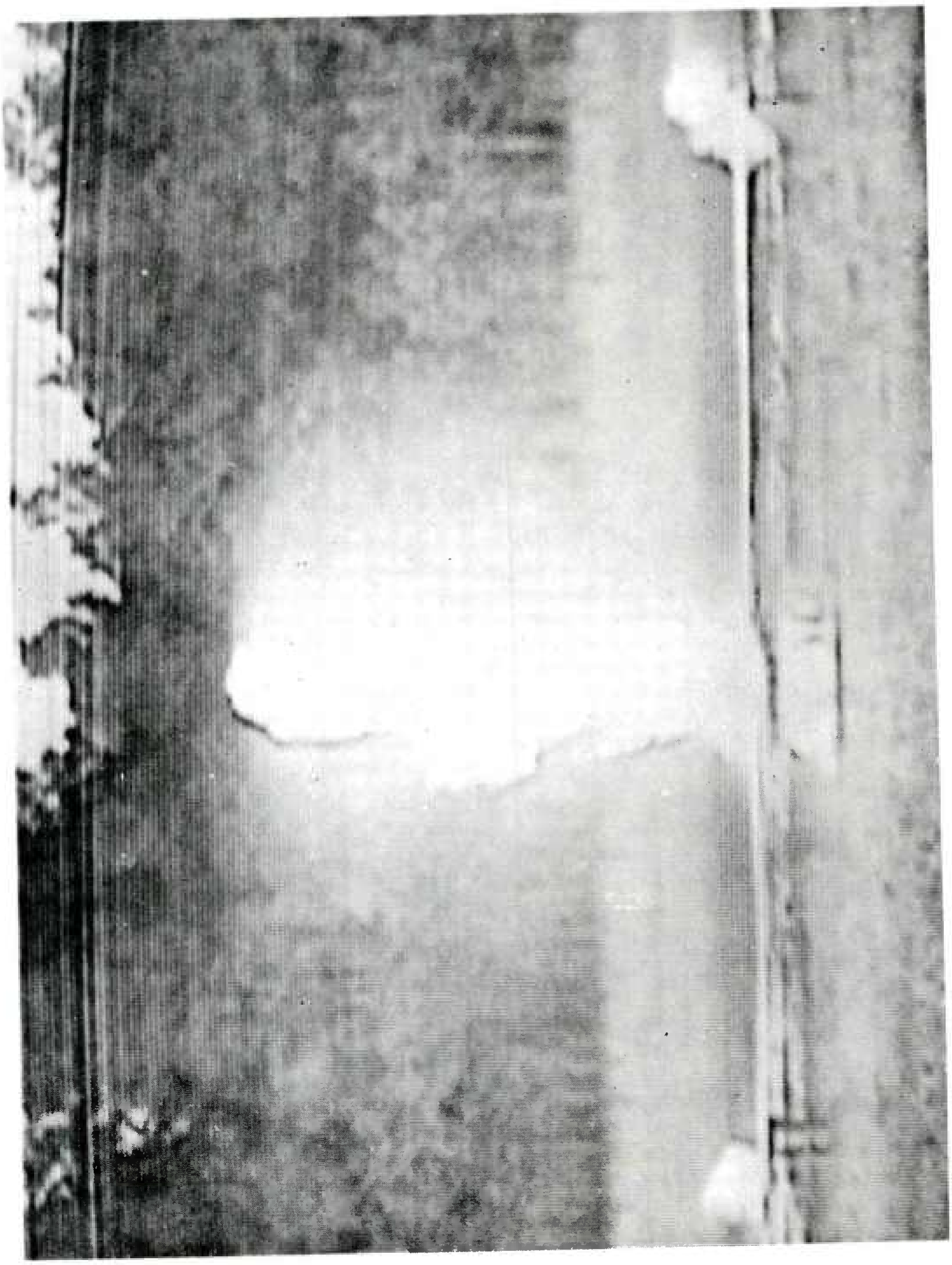

Figure 9. Acceptor fragment impacts

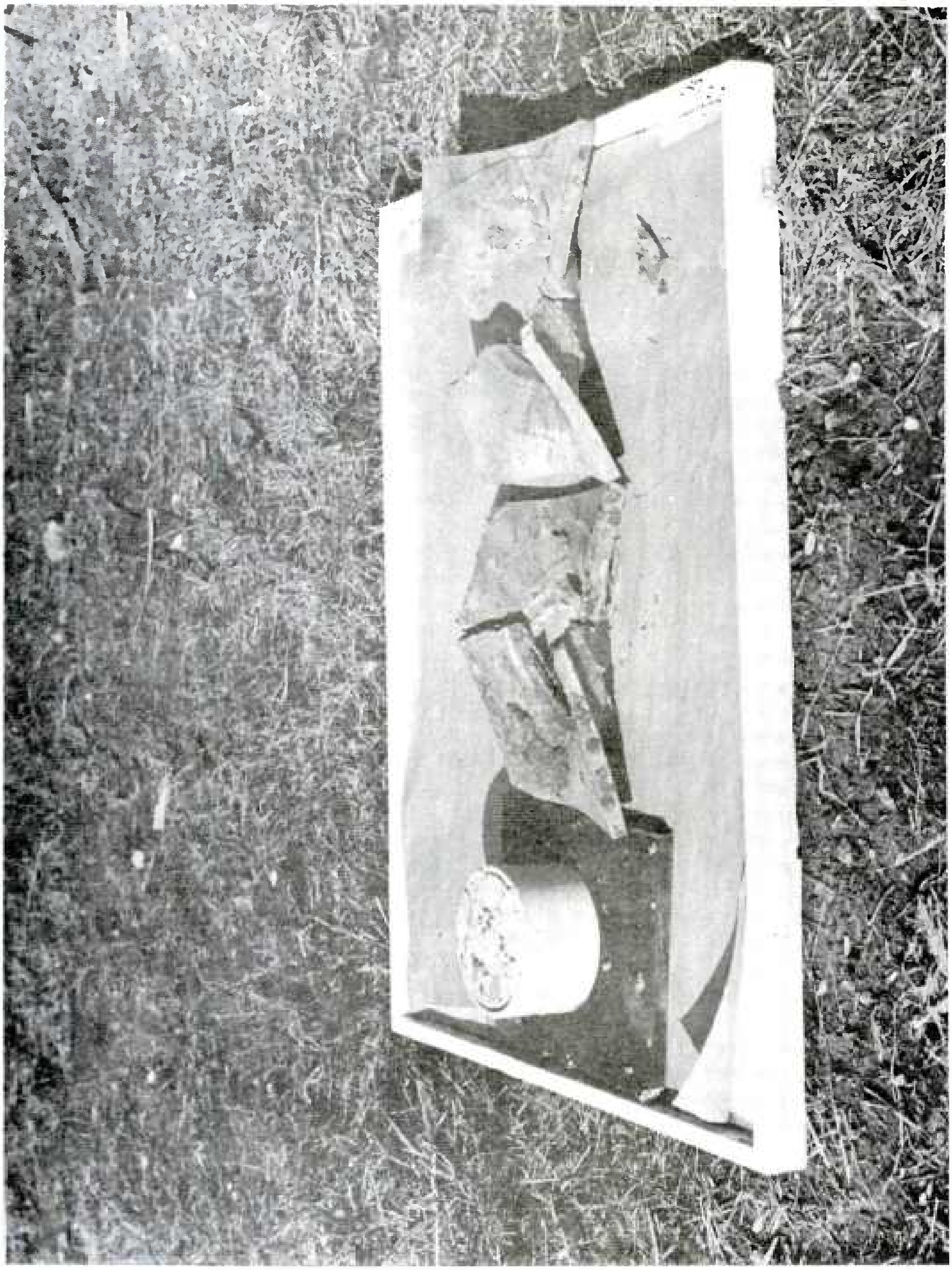

Figure 10. Unbarricaded post-test view

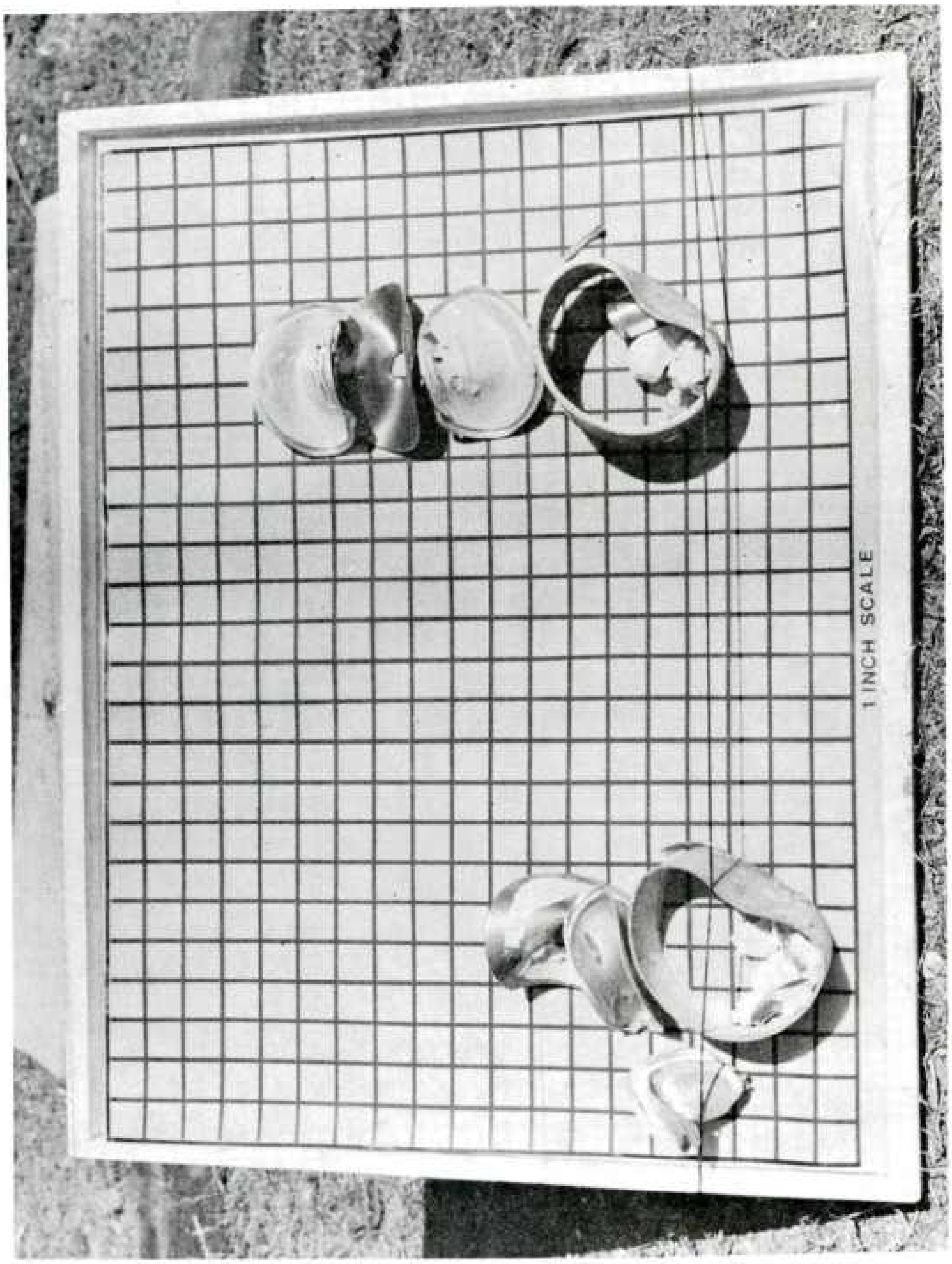

Figure 11. Barricaded post-test view

Figure 12. Barricaded post-test view with recovered barrier

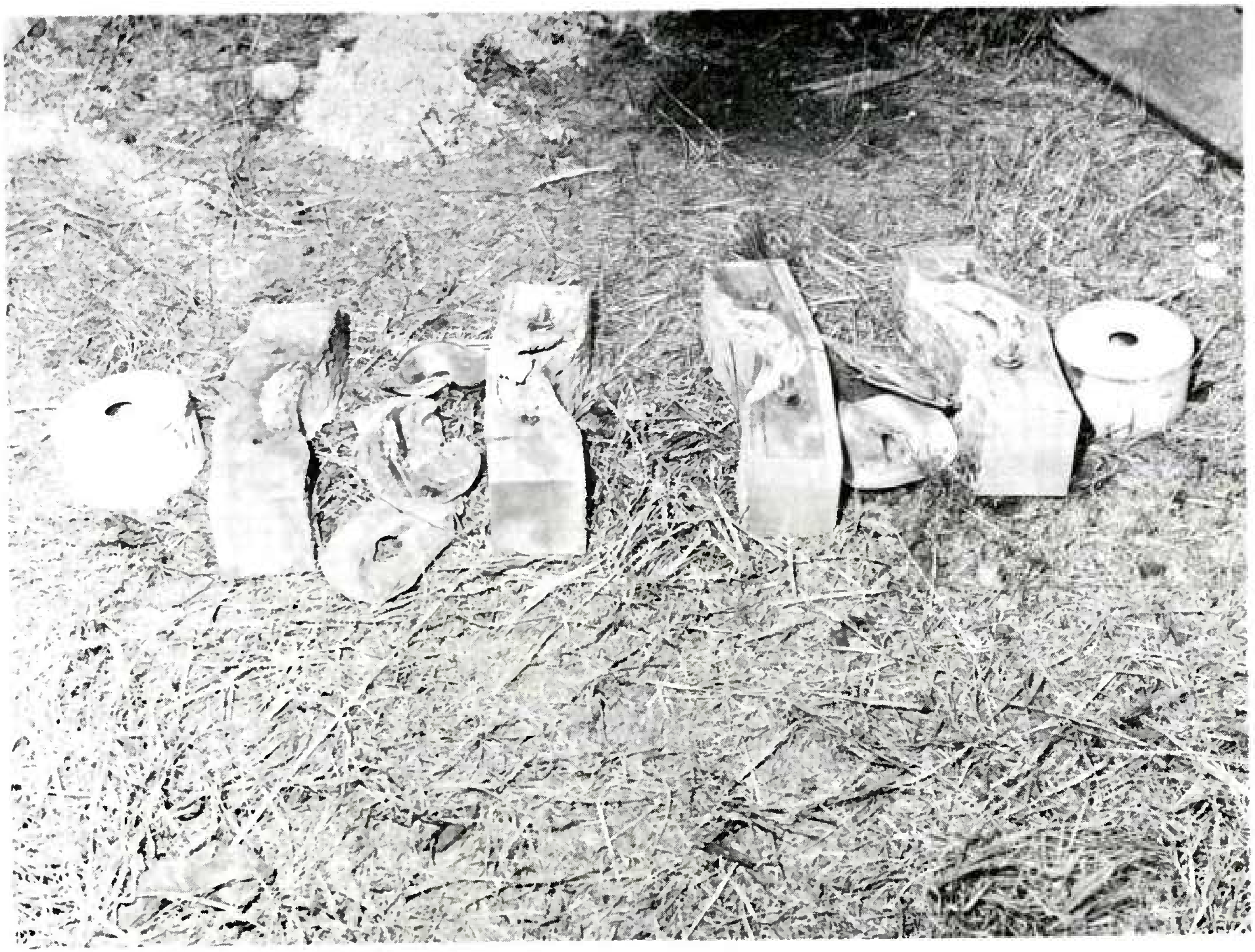

Figure 13. Square barrier, post-test view

APPENDIX

STATISTICAL EVALUATION OF EXPLOSION PROPAGATION

Statistical Theory

The possibility of the occurrence of explosion propagation based upon a statistical analysis of the test results has been evaluated in the main body of the report. This appendix is devoted to the mathematical means by which the statistical analysis was performed.

The probability of the occurrence of an explosion propagation is dependent upon the degree of certainty or confidence level involved and has upper and lower limits. The lower limit for all confidence levels is zero; whereas the upper limit is a function of the number of observations or, in this particular case, the number of acceptor items tested. Since each observation is independent of the others and each observation has a constant probability of a reaction occurrence (explosion propagation), the number of reactions (x) in a given number of observations (n) will have a binomial distribution. Therefore, the estimate of the probability (p) of a reaction occurrence can be represented mathematically by

$$p = x/n \qquad (1)$$

and, therefore, the expected value of (x) is given by

$$E(x) = np \qquad (2)$$

Each confidence level will have a specific upper limit (p_2) depending upon the number of observations involved. The upper probability limit for a given confidence level α, when a reaction is not observed, is expressed as

$$(1 - p_2)^n = \varepsilon \qquad (3)$$

where $$\varepsilon = (1 - \alpha)/2 \text{ and } \alpha < 1.0 \qquad (4)$$

Use of equation 3 is illustrated in the following example:

Example

Determine the upper probability limit of the occurrence of an explosion propagation for a confidence level of 95% based upon 30 observations without a reaction occurrence.

Given

Number of Observations (n) = 30
Confidence Level (α) = 95%

Solution

1. Substitute the given value of (α) into equation 4 and solve for ε:

$\varepsilon = (1 - \alpha)/2 = (1 - 0.95)/2 = 0.025$

2. Substitute the given value of (n) and value of (ε) into equation 3 and solve for p_2:

$$\varepsilon = 0.025 = (1 - p_2)^{30}$$

or

$$p_2 = 0.116(11.6\%)$$

Conclusions

For a 95% confidence level and 30 observations, the true value of the probability of explosion propagation will fall between zero and 0.116; or statistically, it can be interpreted that in 30 observations, a maximum of (0.116 x 30) = 3.48 observations could result in a reaction for a 95% confidence level.

Probability Table

Table A-1 shows the probability limits and the range of the expected value E(x) for different numbers of observations. Three confidence limits, 90, 95 and 99%, are used to derive the probabilities. The same values are plotted in Figure A-1.

Table A-1. Probabilities of propagation for various confidence limits

Number of observations	90%	C.L.	95%	C.L.	99%	C.L.
n	P2	E(x)	P2	E(x)	P2	E(x)
10	0.259	2.59	0.308	3.08	0.411	4.11
20	0.131	2.62	0.168	3.36	0.233	4.66
30	0.095	2.85	0.116	3.48	0.162	4.86
40	0.072	2.88	0.088	3.52	0.124	4.96
50	0.058	2.9	0.071	3.55	0.101	5.05
60	0.049	2.92	0.060	3.6	0.085	5.10
80	0.037	2.96	0.045	3.6	0.064	5.12
100	0.030	3.0	0.036	3.6	0.052	5.2
200	0.015	3.0	0.018	3.6	0.026	5.2
300	0.010	3.0	0.012	3.6	0.018	5.4
500	0.006	3.0	0.007	3.5	0.011	5.5

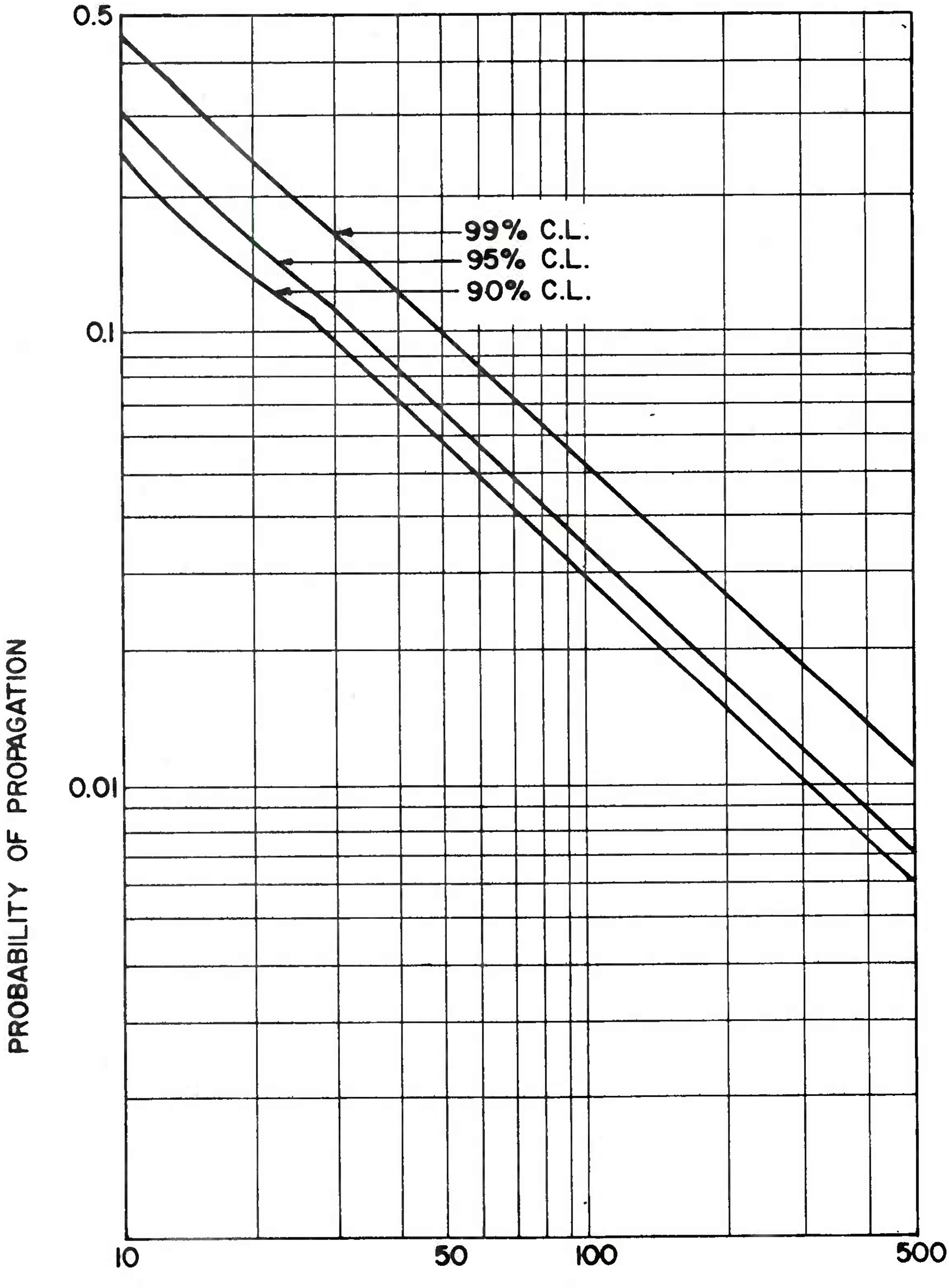

Figure A-1 Variations of propagation probability vs. number of observations as a function of confidence level.

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